

"Express Mail" mailing label number EV 327130855 US

Date of Deposit: September 5, 2003

Our Case No.8285/635  
Client Ref. No. T00129-1

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE  
APPLICATION FOR UNITED STATES LETTERS PATENT

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TITLE:	MOBILE ASSISTED HANDOFF SYSTEM AND METHOD
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## BACKGROUND OF THE INVENTION

### 1. FIELD OF THE INVENTION

The present invention relates generally to digital cellular mobile radio communication systems. The present invention relates more specifically to a method and system for effecting an improved mobile assisted handoff operation as the mobile station moves from one cell to another within a cellular communication network.

### 2. DESCRIPTION OF THE RELATED ART

In cellular mobile communication systems where a mobile station (MS) may be constantly moving, it is essential that the radio communications link with the mobile station be maintained when the station moves from one cell served by one base station (BS) to a second cell served by a different base station. The process of handing over the communications link from one base station to another, in a manner that is transparent to the user, is known as handoff.

The most commonly used criteria to determine the need for a handoff is received signal strength (RSS). In first generation cellular systems such as the Advanced Mobile Phone System (AMPS), the serving base station performs a received signal strength measurement on the signal received from the mobile station and uses this information to make a handoff decision. In such a system and method, there is no mobile station involvement in the measurement or decision making process.

Second generation digital cellular communication systems such

1 as the IS-136 and GSM systems have introduced mobile assisted  
2 handoff (MAHO) where the mobile station assists the base station in  
3 the handoff decision making process by itself performing received  
4 signal strength and bit error rate (BER) measurements.

5 In the IS-136 system, the mobile station performs received  
6 signal strength and bit error rate measurements on the channel it  
7 is currently operating on and only received signal strength  
8 measurements on a list of candidate channels supplied to it by the  
9 base station. The RSS measurements on candidate channels are  
10 performed during the idle period between designated time slots in  
11 the communication link.

12 A technique called Digital Locate has also been developed by  
13 network infrastructure manufacturers that allows candidate base  
14 stations to perform received signal strength measurements on the  
15 mobile station in question and allows the base station to  
16 synchronize to the mobile station's transmissions to verify the  
17 identity of the mobile station.

18 In the GSM system, the mobile station also performs received  
19 signal strength measurements during the idle period between  
20 designated time slots. In addition, since the frame structure of  
21 GSM has one idle time frame per multi-frame, during this idle time  
22 frame the mobile station synchronizes to the broadcast control  
23 channel (BCCH) of a candidate base station and reads the base  
24 station identification code (BSIC) to verify the identity of the  
25 base station. A number of patents, including U.S. Patents Nos.  
26 5,042,082, 5,200,957, and 5,257,401, describe systems within which

1 the mobile station performs received signal strength measurements  
2 on a list of target base station channels. The base station then  
3 supplies the color code information of the mobile station to the  
4 target base stations and the target base stations measure the  
5 received signal strength of the mobile station in question and  
6 synchronize to the mobile station's transmissions to read its color  
7 code.

8 Other patents, including U.S. Patent No. 5,493,563, describe  
9 systems where measurements on voice channels of adjacent cells are  
10 performed. In addition, U.S. Patent No. 5,157,661 describes a  
11 system where a communication test is performed on candidate  
12 channels during the free time of a time division multiplexed  
13 channel.

14 Despite the above efforts at improving the mobile assisted  
15 handoff operation, there are still serious drawbacks to the  
16 accuracy of the systems and their ability to identify and designate  
17 the most appropriate base station to receive the handoff. By  
18 involving the mobile station in the appropriate selection of a base  
19 station handoff, the accuracy improves, but remains a problem even  
20 with the kinds of measurements mentioned in the above patents.

#### 21 22 SUMMARY OF THE INVENTION

23 It is therefore an object of the present invention to provide  
24 a system and method to improve the quality of the handoff decision  
25 by allowing the mobile station to synchronize to candidate base  
26 station transmissions for identity verification purposes, thus

1 reducing the probability of a dropped call due to an erroneous  
2 handoff decision.

3 It is a further object of the present invention to provide a  
4 system wherein a mobile station has the ability to synchronize to  
5 candidate base station transmissions and to read the transmitted  
6 digital voice color code (DVCC).

7 It is a further object of the present invention to provide a  
8 method wherein a mobile station synchronizes to a candidate base  
9 station's transmissions and reads the DVCC, thus assisting in  
10 verifying the identity of the base station.

11 It is a further object of the present invention to provide a  
12 system and method that avoid problems associated with strong co-  
13 channel interferers in the RSS measurements reported by a mobile  
14 station.

15 It is a further object of the present invention to incorporate  
16 into the mobile station certain functions currently performed by  
17 Digital Locate systems, thus permitting the elimination of separate  
18 Digital Locate radio transceivers.

19 It is a further object of the present invention to implement  
20 a system and method for improved mobile assisted handoff that  
21 requires a minimal amount of additional computational and memory  
22 resources in the mobile station.

23 In fulfillment of these and other objectives, the present  
24 invention provides a system and method that give the mobile station  
25 the ability to synchronize to candidate base station's  
26 transmissions in order to read the transmitted digital voice color

code (DVCC). This process is performed during the idle period between two designated time slots in a frame. The mobile station performing the process does not need advance synchronization information regarding the candidate handoff channels in order to read the DVCC. The invention is an enhancement to the existing mobile assisted handoff procedures described in the IS-136 standard. In the existing IS-136 standard, the mobile station performs a received signal strength measurement on candidate base station channels. The present invention improves on the use of received signal strength measurements in that it allows the mobile station to acquire and report information regarding the digital verification color code (DVCC) of the candidate base station channels. Since the DVCC uniquely identifies the cell site to which a channel belongs, it is used to distinguish the candidate base station channel (and its RSS measurements) from its co-channels (and their RSS measurements), allowing the network to make a more informed handoff decision.

In summary, the function of the improved mobile assisted handoff method is as follows:

Step 1: When mobile assisted handoff procedures are activated, the current base station issues a first measurement order containing a list of up to 24 channels for the mobile station to take signal strength measurements on.

Step 2: Upon receipt of the first measurement order, the mobile station begins to measure received signal

1 strength and bit error rate on its current channel and  
2 received signal strength on the candidate channels listed  
3 in the first measurement order. These measurements are  
4 made during the mobile station's idle time slots.

5 Step 3: The measurement results are reported back to  
6 the current base station in the channel quality message.

7 Step 4: Based on the measurement results reported in  
8 the channel quality message by the mobile station, the  
9 current base station selects a number of the most  
10 favorable channels, for example three (3), and issues a  
11 second measurement order to the mobile station with a  
12 list of the candidate handoff channels.

13 Step 5: Upon receipt of the second measurement order,  
14 the mobile station attempts to synchronize to each of the  
15 candidate channels during its idle time slots. The  
16 mobile station reads and decodes the digital verification  
17 color code to obtain the DVCC for each channel.

18 Step 6: The mobile station returns the measured values  
19 of each DVCC to the current base station.

20 Step 7: The network then makes a handoff decision based  
21 upon all of the information provided.

#### 22 BRIEF DESCRIPTION OF THE DRAWINGS

23  
24 FIGS. 1a and 1b are flow charts showing the steps of the  
25 method of the present invention.

26 FIG. 2 is a schematic diagram showing the frame structure and  
27  
28

1 base station to mobile station time slot format for the IS-136  
2 standard.

3 FIG. 3 is a schematic diagram showing a sample time alignment  
4 between a current channel and a candidate base station channel on  
5 which received signal strength and digital color code measurements  
6 are to be made.

7 FIG. 4 is a schematic diagram showing the time offset of the  
8 SYNC word with respect to the CDVCC word in adjacent time slots.

9 FIG. 5 is a graphic representation of the miss rate versus the  
10 C/I for a vehicle speed of 100 Kmph when the allowable number of  
11 attempts made by the mobile to read the CDVCC range from 1 to 3.

12 FIG. 6 is a graphic representation of the miss rate versus the  
13 C/I for a vehicle speed of 8 Kmph when the allowable number of  
14 attempts made by the mobile to read the CDVCC range from 1 to 3.

#### 15 16 DESCRIPTION OF THE PREFERRED EMBODIMENT

17 In a digital cellular mobile communication system such as is  
18 defined by the IS-136 standard, where a number of users are time  
19 division multiplexed (TDMA) into one channel, each mobile station  
20 on the channel transmits and receives in bursts corresponding to  
21 its allotted time slot. Fig. 2 shows the TDMA frame format, and  
22 the base station to mobile station slot format for the IS-136  
23 system.

24 In this format, every TDMA frame (40) supports up to three  
25 users, each using one pair of time slots, for full rate digital  
26 traffic channel operation. Each mobile station is assigned every



1 third time slot, for example; slot 1 (41) and slot 4 (44), slot 2  
2 (42) and slot 5 (45), or slot 3 (43) and slot 6 (46). Thus, each  
3 mobile station is idle for two time slots between its allotted pair  
4 of time slots. This idle period of 13.33 ms occurs once every half  
5 frame and is utilized in the present invention to facilitate mobile  
6 assisted handoff.

7 Fig. 2 also discloses the format of an individual time slot  
8 within frame (40). Each time slot is structured the same as is  
9 disclosed for time slot 3 (43) given as an example. One such time  
10 slot (50) has a duration of 6.67 ms and contains 162 symbols each  
11 of which represents two bits, thus comprising a total of 324 bits.  
12 In the IS-136 format, various digital words are communicated in  
13 specified portions of each time slot. As shown in Fig. 2, time  
14 slot (50) is comprised of SYNC word (51) made up of 28 bits, SACCH  
15 word (52) made up of 12 bits, followed by a first data section (53)  
16 made up of 130 bits. The first data section (53) is followed by  
17 the coded digital voice color code (CDVCC) word (54) made up of 12  
18 bits. A second data section (55) made up of 130 bits then follows  
19 with a single bit RSVD word (56) and a CDL word (57) made up of 11  
20 bits terminating the time slot (50). Of particular concern to the  
21 present invention are the SYNC word (51) and the CDVCC word (54).  
22 It is these two elements of information that are necessary for the  
23 mobile station to accurately identify candidate base stations for  
24 which it is making received signal strength measurements.

25 Reference is now made back to Figs. 1a and 1b for a detailed  
26 description of the steps of the method of the present invention for  
27  
28

1 implementing the mobile assisted handoff. When mobile assisted  
2 handoff procedures are activated (step 10), the base station issues  
3 a first measurement order (step 12) containing a list of up to 24  
4 channels for the mobile station to take received signal strength  
5 (RSS) measurements on. In standard fashion, the mobile station  
6 performs RSS and BER measurements on the current base station  
7 channel (step 14) and reports the measured RSS and BER values back  
8 to the base station via the SACCH word (step 16).

9 The mobile station then measures the RSS on one entry of the  
10 first measurement order list during its idle time slot of each half  
11 frame (step 18). This RSS measurement procedure involves tuning  
12 the mobile receiver to the candidate channel, taking signal  
13 strength measurements, and returning back to the current channel to  
14 be able to receive the next designated slot in time. This  
15 procedure is described in more detail below with respect to Fig. 3.  
16 The mobile station reports the RSS measurement to its current base  
17 station (step 20) in the form of a channel quality message which  
18 may be transmitted in the corresponding 12 bit SACCH (slow  
19 associated control channel) field of the uplink time slot. The  
20 mobile station repeats this RSS measurement process for each of the  
21 candidate base stations in the channel list (step 22).

22 After the mobile station finishes processing the first  
23 measurement order, the base station may wait until the RSS values  
24 on the current and/or the candidate channels cross a threshold  
25 (step 24), before taking any further action. The threshold values  
26 simply indicate when a handoff is both desirable and possible. The

1 base station determines a number, for example three (3), of the  
2 most favorable candidate channels based on the reported RSS  
3 measurements, and issues a second measurement order containing a  
4 list of candidate channels that the mobile should tune to and read  
5 the DVCC.

6 When the mobile station receives the second measurement order,  
7 it must tune to each candidate channel on the list and synchronize  
8 to it (step 28), read and decode the coded DVCC (CDVCC) (step 30),  
9 and then tune back to its current channel, all within 13.33 ms of  
10 idle time. The factors affecting the mobile station's ability to  
11 accomplish this are discussed in more detail below. Once again,  
12 the mobile station repeats the process described (steps 28, 30 and  
13 32) for each of the candidate channels on the list (step 34). The  
14 base station and MSC (mobile switching center) then utilize the  
15 reported received signal strength measurements and the DVCC values  
16 to distinguish and identify plausible (and the optimal) base  
17 stations for handoff, from the inappropriate co-channel interferers  
18 that may have returned high RSS measurements (step 36).

19 Reference is now made to Figs. 3 and 4 for a more detailed  
20 description of the process carried out by the mobile station in  
21 tuning to candidate channels on the second measurement order list.  
22 The ability of the mobile station to carry out the process  
23 described above is affected by a number of factors.

24 First, the candidate channel (60) may not be time aligned with  
25 the current channel (40), so the mobile station has to acquire  
26 frame synchronization by performing a SYNC word correlation. There

1 are six SYNC words defined by the IS-136 standard, and the  
2 candidate handoff channel may contain any of the six SYNC words.  
3 Since the mobile station does not know which SYNC words are being  
4 used in the candidate channel, it must perform a correlation with  
5 all six SYNC words to acquire frame synchronization.

6 Second, even though the mobile station has 13.33 ms of idle  
7 time between its designated time slots, the actual time window  
8 available to detect the SYNC word and read the CDVCC may not be the  
9 full 13.33 ms but something less because the mobile receiver  
10 oscillator requires some time  $t$  to tune between the channels and  
11 adequately settle.

12 Fig. 3 discloses a situation where a mobile station uses slot  
13 1 (41) and slot 4 (44) on its current channel (40). During idle  
14 slot 2 (42) and idle slot 3 (43), the mobile station tries to read  
15 the DVCC from a candidate channel (60). The actual time window  
16 (70) "visible" to the mobile is 13.33 ms minus  $2t$ , where  $t$  is the  
17 time required by the mobile receiver oscillator to tune from one  
18 channel to another. In this example, the candidate channel has a  
19 time offset such that the mobile station can see slot 4 (64) and  
20 parts of slot 3 (63) and slot 5 (65) of candidate channel (60). In  
21 this example, therefore, only one CDVCC word (74) and two SYNC  
22 words (73 and 75) are visible to the mobile. CDVCC words (72 and  
23 76) from slot 3 (63) and slot 5 (65), as well as SYNC word (71)  
24 from slot 3 (63), are not visible. The specific word availability  
25 is entirely dependent upon the time alignment of the current  
26 channel (40) with respect to the candidate channel (60).

1       The time taken by the mobile receiver oscillator to tune from  
2 channel to another generally ranges from 1 to 2 ms. Assuming this  
3 time period to be 2 ms, the time window available for the mobile  
4 station to synchronize and read the CDVCC is  $13.33 - 4$  or 9.33 ms.  
5 Since one time slot is 6.6 ms long, in any alignment at least one  
6 CDVCC and one SYNC word will be visible to the mobile station  
7 during this time window. Since synchronizing to a candidate  
8 handoff channel and reading and decoding the CDVCC are the  
9 essential features of the present mobile assisted handoff  
10 procedure, it is necessary that a non-coherent demodulator be used  
11 at the mobile receiver so as to save the time required to acquire  
12 carrier synchronization.

13       When the mobile station receives the second measurement order,  
14 it tunes to one of the candidate handoff channels in one of the  
15 13.33 ms idle periods. As soon as the receiver oscillator is tuned  
16 to the candidate channel, the output samples of the demodulator are  
17 saved in memory for a period of the visible time window. For  
18 reference and subsequent discussions, let this set of samples  
19 corresponding to the visible time window be denoted by WIN and the  
20 number of samples in WIN be denoted by  $N_s$ . This data is correlated  
21 with the six SYNC words defined by IS-136. These six correlations  
22 may be performed either in serial or in parallel. The algorithms  
23 for both the serial and parallel methods along with their  
24 advantages and disadvantages are described in more detail below.

# SERIAL METHOD FOR SYNC WORD CORRELATION

```

1      initialize peak_corr to all 0's
2      for i = 1 to 6 (number of SYNC words)
3          for j = 1 to (Ns - length of SYNC word) (# of samples)
4              corr = 0
5              for k = 1 to length of SYNC word
6                  corr = corr + WIN(j+k-1)*SYNC(i)(k)
7              end
8              if corr > peak_corr(i)
9                  peak_corr(i) = corr
10                 peak_index(i) = j
11             end
12         end
13     end

```

The advantage of the serial correlation method is that after the peak correlation for one SYNC word has been determined, all the values of the correlation values calculated with respect to that SYNC word can be discarded, thus reducing the amount of memory required for the procedure. The disadvantage is that since the entire process is staggered in time, it takes more time than parallel processing and may require off-line processing after the mobile receiver has return to its current channel.

# PARALLEL METHOD FOR SYNC WORD CORRELATION

```

17     initialize corr to all 0's
18     for i = 1 to (Ns - length of SYNC word)
19         for j = 1 to length of SYNC word
20             corr(1)(i) = corr(1)(i) + WIN(i+j-1)*SYNC(1)(j)
21             corr(2)(i) = corr(2)(i) + WIN(i+j-1)*SYNC(2)(j)
22             corr(3)(i) = corr(3)(i) + WIN(i+j-1)*SYNC(3)(j)
23             corr(4)(i) = corr(4)(i) + WIN(i+j-1)*SYNC(4)(j)
24             corr(5)(i) = corr(5)(i) + WIN(i+j-1)*SYNC(5)(j)
25             corr(6)(i) = corr(6)(i) + WIN(i+j-1)*SYNC(6)(j)
26         end
27     end
28     for i = 1 to 6
29         peak_corr(i) = peak value of row i of corr
30         peak_index(i) = index at value of peak_corr(i)
31     end

```

The disadvantage of the parallel correlation method is the

1 necessity of storing all of the correlation values before being  
2 able to choose the peak correlations. It also requires the ability  
3 to perform six correlations in parallel. The advantage is that  
4 since all six correlations are calculated in parallel, the results  
5 may be obtained much faster than with the serial method.

6       Once the peak correlations for each of the six SYNC words have  
7 been determined, the following algorithm is used to select the SYNC  
8 word that was most likely transmitted along with the optimum offset  
9 location of a CDVCC word from this SYNC word. Reference is made to  
10 Fig. 4 for the relative positions of the CDVCC words (82 and 84)  
11 and the SYNC words (81 and 83) for time slots (86 and 88) in the  
12 candidate channel (80).

#### 13                   OPTIMUM PEAK SEARCH

```
14     best_peak = 0
15     best_peak_index = 0
16     for i = 1 to 6
17         if peak_corr(i) > best_peak
18             is peak_index(i) such that the CDVCC samples at 71
19             symbols after the SYNC word are within the visible
20             window ?
21             if yes,
22                 best_peak = peak_corr(i)
23                 best_peak_index = peak_index(i)
24             else,
25                 is peak_index(i) such that the CDVCC samples
26                 (corresponding to the previous slot) at 91
27                 symbols before the SYNC word are within the
28                 visible window?
29                 if yes,
30                     best_peak = peak_corr(i)
31                     best_peak_index = peak_index(i)
32                 end
33             end
34         end
35     end
```

25       The above algorithm ensures that as long as there is one SYNC  
26 words and one CDVCC present within the visible time window, the

1 mobile station will be in a position to read the CDVCC if the  
2 correct SYNC word can be detected. Based on the outcome of this  
3 algorithm, the samples corresponding to the CDVCC are demodulated  
4 via classical "hard decision" techniques. (Samples are compared to  
5 a threshold, with bit decisions dependent upon whether the sample  
6 is greater or less than the threshold.) The resulting CDVCC bits  
7 are then decoded using a (12,8) shortened Hamming code decoder to  
8 give the DVCC. The mobile station may then use the SACCH field in  
9 its uplink slot to transmit this received DVCC back to its current  
10 base station. After the DVCCs for all of the three candidate base  
11 station channels on the list have been reported, the network has  
12 the information about the signal strengths and the DVCCs for the  
13 three most likely handoff channels and can make a handoff decision  
14 accordingly.

15       This information is useful in situations where the candidate  
16 base station channel has a strong co-channel interferer because in  
17 such a case the RSS value reported by the mobile station may give  
18 a false indication of the actual signal strength of the channel.  
19 If the network does not have any other information apart from the  
20 signal strength reported by the mobile station, it may hand the  
21 mobile off to this candidate base station channel (whose reported  
22 RSS value was high but actually the signal strength was low),  
23 resulting in a dropped call.

24       This improved mobile assisted handoff function on the mobile  
25 receiver requires that a certain amount of computational power and  
26 memory be available on the mobile station. The amount of time



required to perform the additional functions may depend upon hardware factors such as memory and the digital signal processor available on the mobile receiver. Estimates regarding the additional amount of processing and memory required to implement the mobile assisted handoff procedures of the present invention may be calculated as follows.

**Processing Capacity:**

Operations required to perform six correlations:  
 $38136 * (\text{no. of samples/symbol})$  operations  
(1 operation = 1 multiplication and 1 addition)

**Memory Requirements:**

$454 * (\text{no. of samples/symbol})$  real samples for storing the original time window

$227 * (\text{no. of samples/symbol})$  real samples to store correlation values for serial method

$1362 * (\text{no. of samples/symbol})$  real samples to store correlation values for parallel method

Total:  $681 * (\text{no. of samples/symbol})$  for serial correlation method

$1816 * (\text{no. of samples/symbol})$  for parallel correlation method

Both the memory and operation requirements mentioned above depend upon the number of times a symbol is sampled (samples/symbol) at the receiver. The amount of processing power and memory required therefore increase with an increase in the number of samples per symbol.

To further complicate matters, with poor channel conditions more than one error may occur in the received CDVCC (up to one error in the received CDVCC can be corrected in the Hamming code

1 decoding process) or a SYNC word may not be detected. In both of  
2 these cases, the mobile station may not be able to obtain a correct  
3 DVCC during that particular visible window of time. This situation  
4 can be denoted as a "miss", indicating that the mobile station  
5 missed obtaining a correct DVCC during the attempt. In such an  
6 instance, it must wait for its next idle period for another attempt  
7 on the same candidate channel. Increasing the allowable number of  
8 attempts by the mobile station will increase the probability of  
9 obtaining the correct DVCC for that candidate channel.

10 Simulation results for missed rate versus C/I ratio are shown  
11 in Figs. 5 and 6 for vehicle speeds of 100 Kmph and 8 Kmph,  
12 respectively. The curves indicate that as the number of allowable  
13 attempts by the mobile increases from 1 to 3, the miss rate drops  
14 sharply. These results have been obtained by using two samples per  
15 symbol at the receiver. Table 1 below shows miss rates for the  
16 number of samples per symbol varying from one to six for a vehicle  
17 speed of 100 Kmph, a C/I of 15 dB and one allowable attempt. The  
18 results indicate that the returns diminish in comparison to the  
19 increasing complexity as the samples per symbol exceeds two.

Samples/Symbol	Miss Rate
1	0.099159
2	0.090909
4	0.090009
6	0.082358

24  
25 Table 1

26 These results indicate that in a preferred embodiment of the

1 system and method of the present invention optimum results can be  
2 achieved by utilizing two samples per symbol at the receiver. The  
3 processing power and memory requirements, therefore, in the  
4 preferred embodiment are as follows:

5       **Processing Capacity:**

6               Operations Required to Perform Six Correlations:  
7                $38136 \times 2 = 76272$  operations

8       **Memory Requirements:**

9                $681 \times 2 = 1362$  bits for Serial Correlation Method  
10               $1816 \times 2 = 3632$  bits for Parallel Correlation Method

11       It is worth noting, that the simulation results contained  
12 herein assume "rectangular" pulse shapes. In the actual IS-136  
13 system, low pass filtering is employed in the transmitter as  
14 defined in the IS-136 standard. Filtering is also typically  
15 employed in the receiver. The effect of filtering is to degrade  
16 the performance from that predicted in Figures 5 and 6, but the  
degree of degradation is expected to be negligible.

17       It is anticipated that these processing and memory  
18 requirements are either already within the limitations of existing  
19 digital cellular mobile stations or are within modifications easily  
20 implemented in existing mobile stations. The method of the present  
21 invention is, therefore, capable of implementation within the  
22 current confines of the IS-136 format and the technology associated  
23 with the tuning and data acquisition rates of existing mobile  
24 stations.

25       Although the present invention has been described in  
26 conjunction with a pre-defined format, it is anticipated that the

steps involved in the present invention are applicable under a greater variety of conditions and formats than those described herein. The more specific scope of the present invention can best be identified by reference to the following claims.